Hydrogen Safety for Large-Scale Electrolyzer Installations

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Introduction

Affiliations

- WHA International
- Hydrogen Safety Panel (HSP)

Experience

- Safety consultant for electrolyzer design, system integration, and small- and large-scale installations
- Investigates electrolyzer incidents
- Instructs hydrogen, oxygen, and electrolyzer safety training courses

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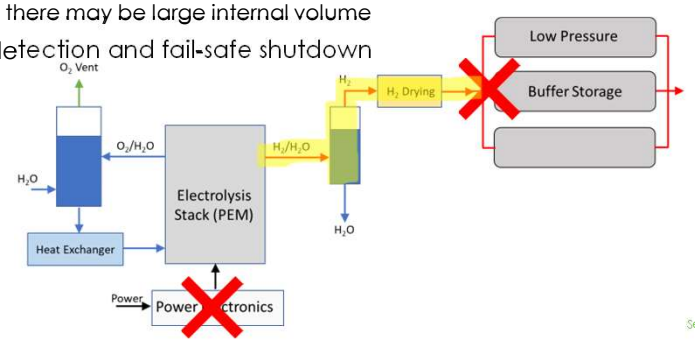
Presentation Outline

- Safety Features for Electrolyzer Systems (PEM, alkaline, AEM, SOE)
  - Inherent Mitigating Factors
  - Inherent Risks and Mitigations
  - Safe Operation
- Oxygen Safety for Electrolyzer Systems
- Scaling Hydrogen Safety
- Cost of Safety
- Resources
- Public Perception and Community Outreach

Safety Features for Electrolyzer Systems

Inherent Mitigating Factors

- Electrolyzer stacks are not storage equipment
  - When current is removed from the stack, production of H2 and O2 stop
  - Assuming storage is isolated and the power removed, only the H2 in the tubing and hydrogen process equipment and may leak out of the system
  - Available quantity reduces consequence potential
    - For large-scale systems, there may be large internal volume
  - Safety relies heavily on detection and fail-safe shutdown



Safety Features for Electrolyzer Systems

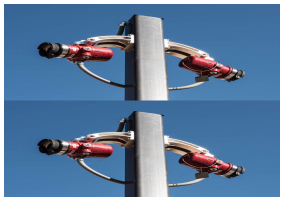
Inherent Risks and Mitigations

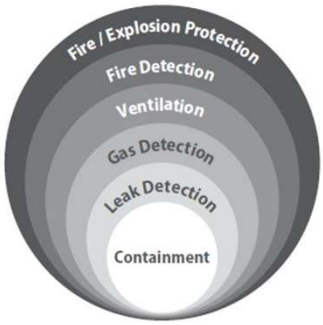
Risks	Best Practice Mitigations
Electrolyzer stacks cannot be electrically classified	• Ventilation is critical across unclassified equipment – ventilation monitoring used to ensure ventilation is active • Classified electrical auxiliary equipment used in electrolyzer system if it stays on during an event • Classified electrical equipment used in compression and storage area • All unclassified equipment shuts off during system automatic shut down • Voltage and current to powered equipment is limited to reduce electrical ignition risk • Proper bonding and grounding reduces risk of electrostatic discharge ignition

Safety Features for Electrolyzer Systems

Inherent Risks and Mitigations

Risks	Best Practice Mitigations
External leaks are likely in pressurized H2 systems	• Joints and fittings minimized to reduce number of leak points • Regular maintenance and leak checks to keep leaks small • Compatible materials and factor of safety used to prevent hydrogen embrittlement failures • Leak and flame detection • Ventilation monitoring • Pressure and/or flow monitoring





Safety Features for Electrolyzer Systems

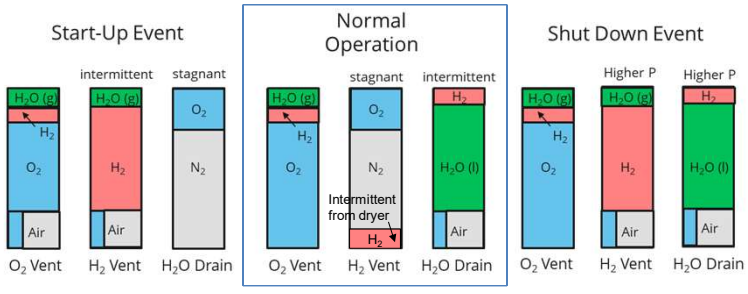
Inherent Risks and Mitigations

Risks	Best Practice Mitigations
Cross-over may result in flammable mixtures on the H2 or O2 side • More likely at start-up and stack end-of-life Recombiners and Deoxo reactors are not capable of mitigating high concentrations and may act as an ignition source	• Experimentally determined during all operational modes and throughout equipment life cycle by manufacturer • Stack not operated below the turn down ratio specified by the manufacturer • On O2 side: H2 sensor within O2/water separator and/or temperature monitoring on recombiner • On H2 side: Deoxo equipment with temperature monitoring
Stack rupture or pinhole leaks may enable mixing of H2 and O2 • More likely at end of life • Accelerated stack degradation may occur due to poor water quality • Loss of coolant may lead to overheating	• Gas mixture analysis • Pressure and/or flow monitoring • Temperature monitoring for the stack • Active cell monitoring (may not provide reliable fault detection under all scenarios)

Safety Features for Electrolyzer Systems

Inherent Risks and Mitigations

Risks	Mitigations
Improper disposal of outlet process streams • Water in the H2 product stream contains dissolved hydrogen • Vents contain water which can freeze	• O2 and H2 vents separated • Disposal of waste water allowed to de-gas in a well-ventilated space away from ignition sources • Dedicated drains used to prevent migration of flammable gas • Freeze protection on vents



Safety Features for Electrolyzer Systems

Fail Safe State

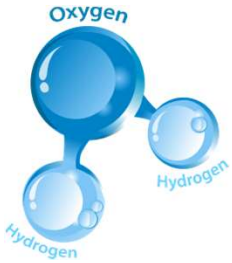
- Automatic shut-off of non-electrically rated equipment including the stack
- Automatic isolation of storage vessels
- Automatic controlled venting of pressurized H2 and O2 gas volumes within system (vessels and tubing) to compliant outdoor vent stack
- Ventilation remains ON

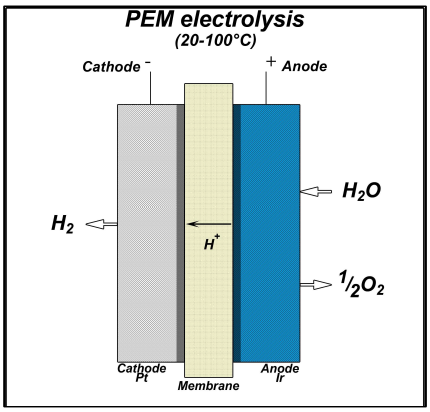
Safe Operation of Large-Scale Electrolyzer Facilities

- Approved procedures for operation, maintenance, and emergency response
- Training and awareness of electrical, O2, and H2 hazards
- H2 specific monitors commonly worn in open areas where fixed gas detection is not possible
- H2 pressure is never relieved by cracking a fitting
- Purging with inert gas before and after maintenance
- H2 fires are put out by stopping the flow of H2, not by extinguishing with water or fire extinguishers

O2 Safety for Electrolyzer Systems

- In all water electrolyzers, O2 is produced at half the molar H2 production rate
  - 1 MW electrolyzer producing ~450 kg/day will also produce ~3570 kg/day 100% O2
- Oxygen hazards are often overlooked when installing and using electrolysis systems





$H_2O \rightarrow 2H^+ + \frac{1}{2}O_2 + 2e^-$		Anode
$2H^+ + 2e^- \rightarrow H_2$		Cathode
$H_2O \rightarrow H_2 + \frac{1}{2}O_2$		Total Reaction

O2 Safety for Electrolyzer Systems

Oxygen Hazards

Material flammability

- All nonmetals are flammable in 100% O2
- Metals also become flammable as O2 pressure and % increase

Ignition sensitivity

- Energy required for ignition decreases
- Materials of construction may ignite via compression heating, particle impact, and others

Combustion consequence

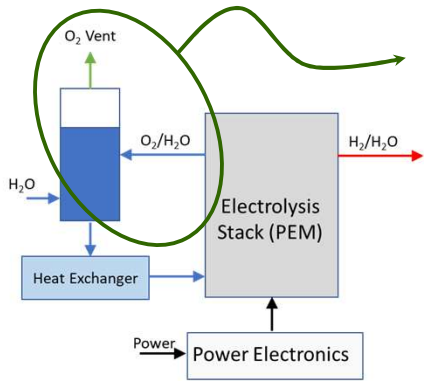
- Higher heat release from fire
- Potential to involve otherwise "burn-resistant" materials
- Higher overpressure from explosions

As O2 P, T, and % increase…

flammability, ignitability, and damage potential also increase

O2 Safety for Electrolyzer Systems

Inherent Risks and Mitigations



- If O2 is pressurized, bulk metals may be flammable and ignition more likely
- Best practice mitigations for pressurized O2 safety
  - Maximalize compatible materials
  - Minimize ignition mechanisms
  - Start and maintain clean
- Some PEM systems operate O2 side near ambient
  - Low pressure high moisture content reduces O2 fire hazard
  - Bulk metals are not flammable in ambient pressure, 100% O2
  - Ignition of materials and contaminants is less likely

O2 Safety for Electrolyzer Systems

Oxygen Safety Regulations for Electrolyzers

- Outdoor vent outlets
  - Free from ignition sources
  - Located at a safe distance from the H2 vent outlet and building air intakes
  - Code references:
    - EIGA Doc 154 09 E, Safe Location of Oxygen and Inert Gas Vents
    - EIGA Doc 211 17, Hydrogen Vent Systems for Customer Applications
    - CGA G5.5, Hydrogen Vent Systems
- Indoor applications
  - Sufficient ventilation provided to prevent oxygen-enriched atmospheres above 23.5%
  - Code reference:
    - NFPA 2 Hydrogen Technologies Code 2020, 13.3.1.2.2, Ventilation for Indoor Electrolyzers

Scaled H2 Safety

- Safety considerations as on-site storage increases
  - Isolation strategies become more important to limit secondary effects
    - E.g. Pressure protection is used to protect storage vessels from external fire, but should a single vessel venting result in venting all storage volumes?
  - Severity of consequence is minimized by
    - Ventilation
    - Fail safe systems
    - Flow restrictions which control leak rates
    - Reduced quantities of H2 stored inside
    - Separation distances
    - Many other best practices…
- Pressure safety is important regardless of stored volume

Cost of Safety

- Prevention is cheap compared to the cost of an incident
- Specialized safety equipment required (e.g. fire eyes, classified detectors)
- H2 is unique and therefore safety approach is different than other pressurized fuels
  - Operations, maintenance, and engineering personnel require specialized training
    - Design differences for best practice and code compliance
      - Must be able to manually or automatically vent all volumes through compliant vent stack
      - Vent stacks must be up and away for buoyant flammable gas release
    - Operations and maintenance considerations

Resources

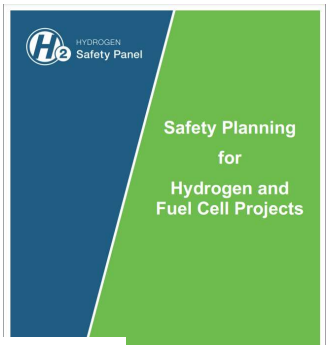
- Codes, standards, and guides for best practices
  - ANSI/CSA B22734 Hydrogen generation using water electrolysis (ISO 22734)
  - ANSI/CSA FC1 and FC6 (IEC 62282)
  - NFPA 2

Model Installation Codes

Product Safety Standards

Resources

- Safety planning guide by HSP
  - Large integrated systems require coordination of safety from many different companies
    - Safety plan is a valuable tool to develop a unified approach to safety
- Hydrogen Equipment Certification Guide by HSP
- Early engagement
  - Authority Having Jurisdiction (AHJ)
  - First responders
- Hydrogen safety consultants
- Training courses



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AIChE/CHS Hydrogen Safety Resources

On-demand Webinars

AIChE INSTITUTE FOR LEARNING & INNOVATION

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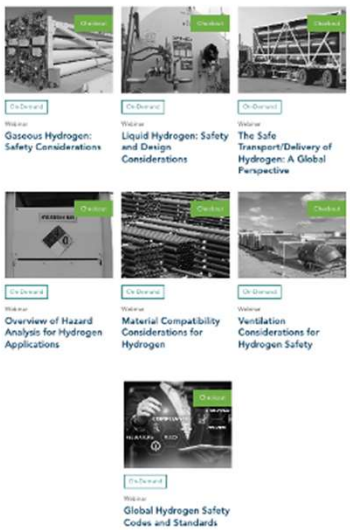

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eLearning Courses

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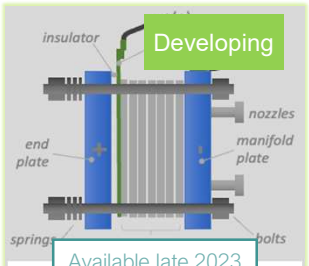

Available late 2023

eLearning Course: Safety of Water Electrolysis Systems

Public Perception & Community Outreach

- Fundamental knowledge
  - Electrolyzers are electrical devices which split water into H2 and O2 – they are not storage vessels and have very little H2 in the device
  - On-site storage vessels are not bombs – they are filled with 100% hydrogen which is not flammable
  - Systems are designed for early detection of H2 releases and safe shut down
  - Hydrogen is highly buoyant and dissipates in the air – it does not accumulate near the ground like liquid fuels (e.g. gasoline, diesel)

- Addressing concerns
  - H2 is not a health hazard and is safe to vent in small quantities into the atmosphere
  - H2 recombines with oxygen to make water and does not produce carbon emissions
  - Research is ongoing on the interaction of H2 in the ozone, but the global warming potential (GWP) of hydrogen is estimated at ~5.8 while methane is ~28 [MIT 2006].

Thanks for Your Attention!

CENTER FOR Hydrogen SAFETY
Connecting a Global Community

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